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Hierarchization of characteristics applied to the component approval strategy

A. Van Hoecke*

Schneider-Electric, Innovation Efficiency, 37 quai Paul Louis Merlin, 38050 Grenoble Cedex France

Abstract

The ISO GPS standards define how to specify, and how to verify each specification. Other international standards define how to ensure the capability of a characteristic. But if capability studies are adapted to "CTQ"(critical to quality) or "key characteristics", they cannot be applied to all. This paper presents the component approval strategy employed at Schneider Electric in order to verify all characteristics, with the appropriate effort, as well as mastering the design process and the robustness of the product.
The functional characteristics have been ranked into four levels by their criticality.
The criticality integers the severity of a failure, the contribution of the characteristic in the functional conditions, and the risk of non conformity due to the process.
This process illustrates one use of the standard NF E 04-009 ("HCPP")

Selection and peer-review under responsibility of Professor Xiangqian (Jane) Jiang

Keywords: capability; functional design; verification; approval; inspection; HCPP; lean design; FMEA; statistical tolerancing

1. Introduction

1.1. Current situation in mechanical industries

3D CAD models and drawings of our components contain numerous requirements. Indeed the 3D model must contain the complete geometrical definition in order to manufacture the part. In addition, the 2D drawing often provides most of the dimensions, because the drawing is contractual by default.

It is not possible to hold a capability study on all characteristics. So usually a functional analysis is launched and allows the identification of "critical" or "key characteristics": the list can be completed or adapted by design and/or process FMEA, and the key characteristics are put under control by capability study or Statistical Process Control.

The concern is then to define how to handle the remaining characteristics, sometimes the most numerous. One way is to ask the supplier (or the workshop) for a "first article inspection report" (FAIR). Often it follows an industrialization or purchasing procedure, where the main aim is to pay the supplier according to "conformity" to the specifications.

The first question that arises is, how many samples? Is one sample sufficient, when considering process variability?

If several samples are required, what acceptance rules should be defined? Are they consistent with the "key characteristic" treatment?

How is it connected with the dimensioning scheme, if some "non key" characteristics are toleranced explicitly?

The project team must satisfy these questions to ensure the quality of products produced by the industrial process.

* Tel +33 4 76 57 78 39; fax: +33 4 76 57 73 76
Email address: alain.van-hoecke@schneider-electric.com

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1.2. . Motivation of the project

In 2003 Schneider Electric had numerous procedures for qualifying its mechanical custom components, due to the history of its companies (Merlin Gerin, Telemecanique, Square D and many others). An internal standardization program was launched with the objective to "unify the best", as Global Technical Centers were created and worked for all brands.

A multidiscipline project team was created with the objective to define a common process for "mechanical components verification", methods and a software tool, for which the author was project leader.

1.3. Situation in 2003: previous works

All our companies lead capability studies (according to different national or international standards like NF E 06-181, NFX 06-030, ISO8258..) on key characteristics (with differences on the way to define them). But this operation was done after the FAIR, which is a global metrology of the part. The statistical rules for the FAIR were poor, except a legacy method well deployed called "63%" created by Zaludova-Forestier [1].This method brought the advantage to force centering (managing involuntarily statistical dimensioning), but was driven only by supplier risk, despite the appearance of reducing the tolerance range. Also it offered no continuity with the capability study, and could result in a low Cpk. Of course testing the simple conformity to the tolerance range, also used, was worse still.

One entity had defined a "variable Cpk" method [2], which assigned a Cpk required according to a Cpk target, the sampling and a customer risk. The Cpk target was identical for each level of criticality, but the customer risk was assigned according to the criticality. This customer risk defined a confidence interval around the Cpk target (NFX 06-027).

Another feature, the criticality of the characteristic was a function of the criticality of the functional condition and the weight of the characteristic in the functional condition, allowing hierarchization. (Weight is defined in appendix E)

This method offered a consistent continuity between the levels of criticality (as many as necessary), but neglected the supplier risk. It was design-oriented (did not take the process risks into account), but forgot the centering requirement issued from statistical tolerancing.

Another entity established a method to define the inspection plan from a criticality based on the severity of a failure and the occurrence, related to the process, according to FMEA principles (1991)

With help of Maurice Pillet's book "Appliquer la maitrise statistique des procédés" , the willingness to use ISO standards, and the participation to UNM08 commission (Union de Normalisation de la Mécanique) , we had considerable material to support the project. From 2005, the revision of NFE04-009 allowed exchanges on the method with attendees, especially Renault SAS.

1.4. Aim and objectives of the project

During 2003-2004 the project team worked out a consistent and unique process (Mechanical Component & Sub-assemblies Verification, MCSV) transverse to the three functions impacted in development (design, industrialization, purchasing) to master the important as well the less important characteristics, whether toleranced or not, during approval, with the first aim being to satisfy the designer's explicit or implicit expectations.

The first part of the paper will describe the design process and show where MCSV stands. Then MCSV will be detailed with a focus on the interfaces.

2. Context: design process

Our design process is called RADAR, (Required Activities of Design to Achieve Robustness). RADAR is dedicated to Electro Mechanical activities, itself a brick of the "One Design" process, describing System Engineering development

2.1. Radar

2.1.1. Overview

RADAR splits the main activities according to a V model as shown on Figure 1:

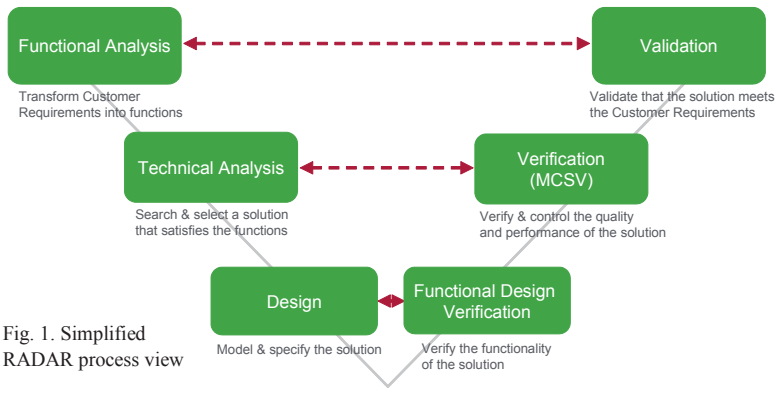


Fig. 1. Simplified RADAR process view

RADAR can be split into 3 main parts, for historical reasons as well organization and information system reasons.

2.1.2. First part: the downstream part of the V is called " Functional Design Process "(FDP)

Customers Requirements are transformed in Technical Function. At each step the risks are identified (a severity level is assigned) and the traceability established.

FDP activities ensure the detailed design begins with the optimal architecture and best technical solution available.

2.1.3. Second part: detailed design (bottom of the V)

These activities ensure production tooling can be launched with a design (of the product and of the process) "verified". The robustness of the design is required and verified.

2.1.4. Third part: verification and validation (upstream part of the V)

These activities cover the physical Verification of components, product or system and its validation.

So it is admitted that MCSV is a consistent part of the design process.

2.1.5. Traceability

The intent of the process and the associated tools is to link the activities together by a "backbone"

RADAR is a transformation process starting from requirements.

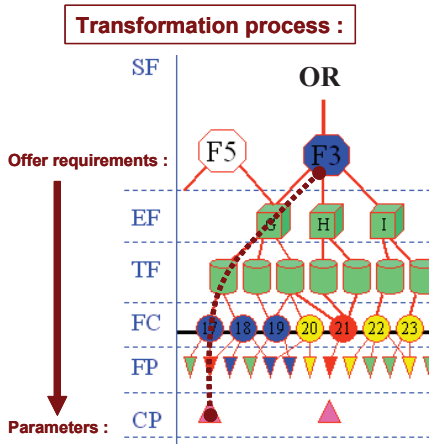


Fig. 2 Transformation process

The objective is to track the quality of Customer requirements all along the product life cycle, from its creation to its recycling.

2 principles:

-Build the bi-directional relation between a Customer requirement and the functional parameter(s) which characterize(s) it.

-Manage the "risk" at each transformation step and attribute to the risk a "severity" indicator.

The most important deliverable of FDP, to ensure this traceability of the requirements, is the FCD (functional condition dashboard).

2.1.6. Functional condition dashboard.

The FCD manages the Service Functions (SF), Technical functions (TF), and Functional Conditions (FC).

It manages their links, and supplies the structure to manage their verification: design verification (ie "verification by simulation" or with "engineering or manufacturing prototypes"), and in upstream branch of V, their physical verification and validation.

At the end of FDP, the FCD contains the functional conditions with their severity.

2.1.7. Specifying and managing Severity.

The objects: Service Functions, Technical functions, and Functional Conditions, carry a severity, defined during the preliminary risk analysis, and then during the FMEAs (failure mode and effect analysis).

The severity is aligned to the customer impact of failure, and is only design dependent.

The severity is propagated through the links; we found no simple rule to automate it: ie the customer can change during the lifecycle. (note that many failures affect the manufacturing plants)

Despite this, the severity is stable and invariant, not supplier dependant, so it is an attribute of the specification.

2.1.8. Deliverables of the design phase

From the traceability/RADAR point of view, you can see that the Functional parameters (FP) are our deliverables, with a severity assigned. So MCSV will manage them.

3. MCSV process

3.1. Qualification concepts:

Qualification exists to ensure components and sub-assemblies conform to *expectations*, and to ensure process means are likely to comply with specifications in the long term.

Qualification covers two activities :(figure 3)

1. Mechanical Components and sub-assembly verification (MCSV) : MCSV can be seen as

the qualification of the "part", decided by Design from a product point of view.

2. Qualification of production process, at the supplier or within Schneider-Electric, is dedicated to master the repeatability of the process, from the pilot run throughout mass production.

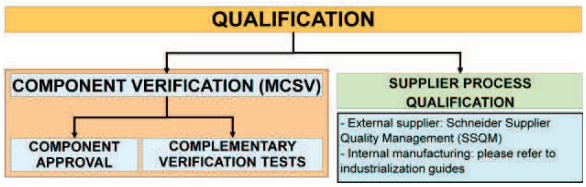


Fig. 3: Qualification Concept

Approval consists of checking a component's conformity to specifications. It is based on statistical control of initial samples, which are representative of components manufactured during regular production runs.

Complementary Verification Tests check component's suitability in the product and/or industrial process context; they cover what could not be fully specified, and for this reason is not the responsibility of the supplier.

3.2. What is a good MCSV process?

To meet business requirements, the process should:

3.2.1. give confidence in the results:

For that we enforced the non normality algorithms, to improve relevancy of the results, and make all requirements verified in one way or another.

3.2.2. be predictive, prevent problems:

Verification of the feasibility of design, and the assessment of process risks before tooling with the tool maker or the supplier; this avoids over quality as well as quality lacks and tailors the efforts. Of course ISO dimensioning is mandatory, , to get unambiguous specifications. MCSV plans the long term, with the drafting of the Component Quality Control Plan (CQCP) with quality specialists.

3.2.3. allow to be taken easy and right decisions:

MCSV ensures a high correlation between conformity of functional parameters of the parts and FC of the products, by characterizing what are the designer's hypothesis during design and verifying them. The designer starts the process, has in mind what he will do if the criteria is rejected. This encourages verification of the characteristic's impact during specification; and so limits over-dimensioning.

3.2.4. be efficient:

Specifications contain necessary & sufficient information, require just the necessary measurement effort. This is achieved through the criticality levels, and the use of modern solutions to avoid direct measurements for low criticality. The criticality recovers data from tolerance analysis, and helps designers to take into account the contribution of the criteria in the FC dispersion. Efficiency would not have been achieved with the single use of the severity, or if we focused only on process risks. Full criticality is mandatory.

3.2.5. minimize the loops to get an accepted part,

This is achieved by promoting the FC simulation from the measurement results at the decision making, and is the consequence of defining just the necessary verifications. *MCSV considers that designer's expectation about the components is to get the related FC satisfied.*

4. Description of MCSV process:

4.1. Schematic MCSV process:

The fundamental criticality principle implies to involve Design function first, and then Industrialization (figure 4)

The "Risk analysis" activity is held in a meeting in which the multi-function team defines what must or can be verified in the MCSV reports, and later, during production phase. In other words, the Verification Plan (VP) and the Quality Control Plan are processed in a collegial way. From the VP, reports are created.

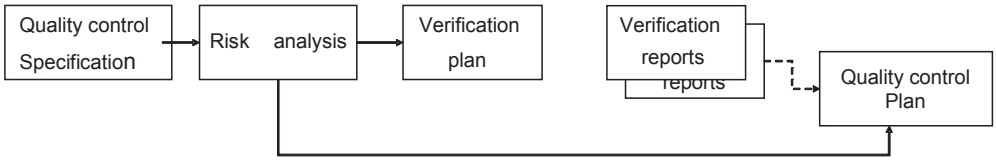


Fig.4: Schematic MCSV process

The flowchart below (figure 5) describes the deliverables, work breakdown structure and the responsibilities in the process.

We will then detail the methods of MCSV to achieve the deliverables.

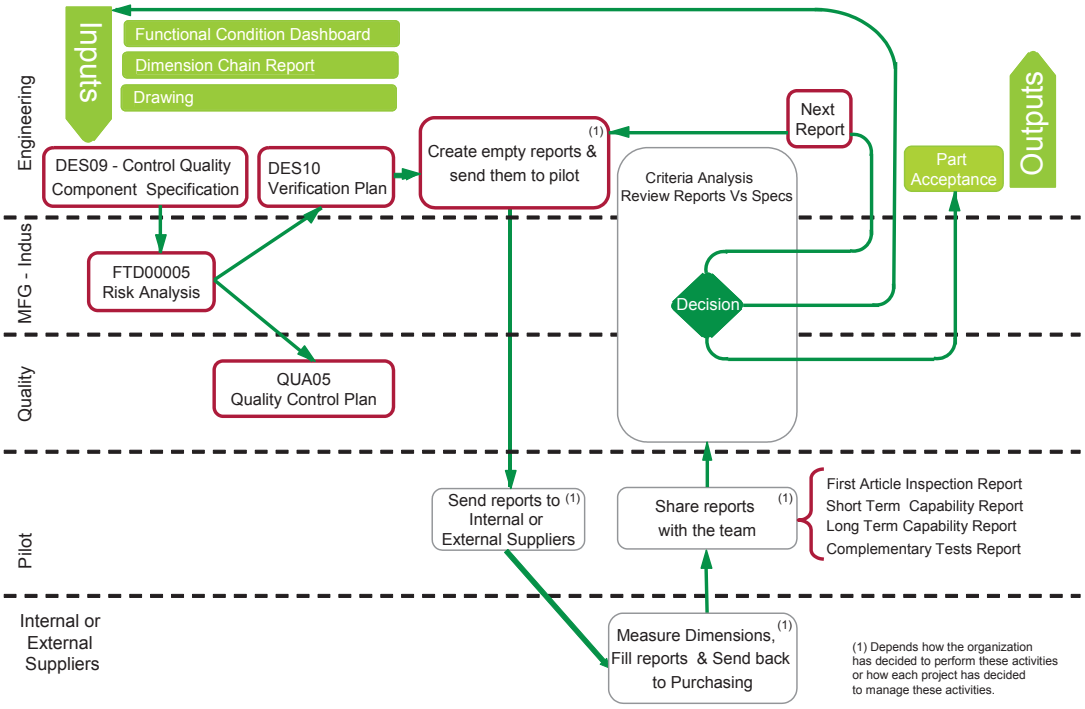
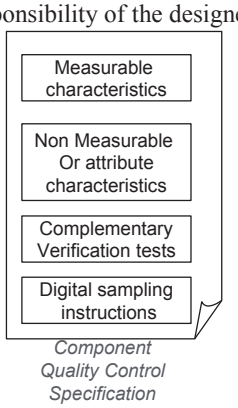


Fig.5: Detailed MCSV process

4.2. Component Quality Control Specification :(CQCS)

The start point of the MCSV process is the Component Quality Control Specification , which is the responsibility of the designer.



It contains (figure 6) the list of functional characteristics, classed by severity and with the expected quality level and the statistical attributes

If necessary, the verification methods are defined

The CQCS covers explicitly or indirectly all the requirements.

Fig.6: CQCS content

Note that some Functional Conditions can be specified (Complementary verification tests)

Let us see what is needed to define the CQCS.

4.3. prerequisites for CQCS

4.3.1. The input deliverables or activities from FDP and design consist of:

1. Functional analysis
2. Drawings with ISO Dimensions
3. Technological specifications
4. Product FMEA, Process FMEA (for industrial severity and occurrences)
5. Functional condition dashboard
6. Dimensional chain report from TM

4.3.2. In addition, RADAR/MCSV require a "quality" of design:

1. To have characterized the functional conditions as much as possible.
   Indeed, it is desirable to be able to define the root cause of a failure of a functional condition involving several parts.
2. To have optimized the tolerancing. (concept of *lean design*)
   We appraise the functions and the parameters with 2 criteria: Severity and Risk of non conformity.

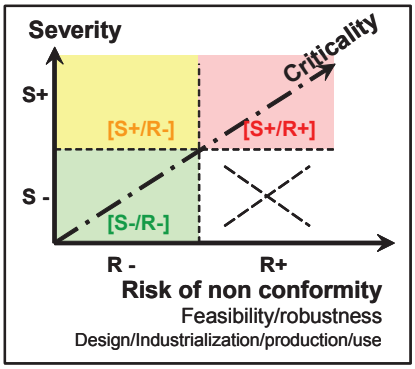


Fig.7: Risk of non conformity

[S+/R+] : Need for optimum control of design and manufacture

[S+/R-] : S+ indicates complete specification & verification are necessary., and R- greater safety margins then allows workload reduction.

[S-/R-] : Specification/verification can be far lighter as the R- announces a small risk of problems, the S- indicates only minor consequences in the event of a problem

3. The rule is to have justified each specification.

Their influence must be verified (especially geometrical tolerances) and simulated.

4. Respect rules for the FC's study and "verification":
   a. Model the dimensional (and other physics) functional conditions,
   b. Model functions at highest level (superficially),

The more precisely the service function can be modeled, the more the interactions and influence of the functional parameters will be accurate. Otherwise the importance of functional conditions contributing to a function cannot be rated.

   c. Choice of technology and tolerance ranges

At preliminary design the tolerance ranges should come for standard tolerance tables, with normal class

(ISO 2768, NFT58000….). If a smaller tolerance is necessary, the designer needs confirmation from advanced manufacturing.

   d. Determine the Distribution laws/dimension model, for FP involved in dimension chains or not. (refer figure 8)

Distribution law is related to the industrial process or to the hypothesis we set. In statistical tolerancing the models integer 3 causes of variation: permanent excentering, random excentering, spread. The tolerance range is the envelop at 3 sigmas of the worst mean.

The model impacts the calculation of the statistical dispersion range of the FC, because global standard deviations are different. It defines the long term statistical criteria of spread and centering that Phenix will verify.

   e. Enter level of severity of functional conditions, according to the FCD.

The minimum quality level is defined directly by the severity (customer effect) the project teams can define more severe ones

(refer figure 9)

FC severity	Ppm design& verification
Safety	3.4
Working	34
Performance	340
Imperceptible	(2700)

Fig.9: Quality level assigned to severity levels

   f. Adjust the model (correlate simulation with prototypes)

This activity is mandatory to achieve the FC targets with the final process.

5. Take the contribution into account

For each dimension a "pseudo" severity will be assigned, (rule in figure 10) read directly in the TM tool (appendix A) and reported in the CQCS.

HCPP standard [1] calls it "class".

This pseudo severity (it is rather a design criticality) is put in the CQCS. Please refer to appendix E to have justification of the 15% limit value.

							comment
	coef (TM tool)=	Cpk worst case	CC LgT	permanent mean shift	random excentering	instantantaneous dispersion	coeff if the parameter setting the limit of the mean. CC is the long term centering of the mean.
<ST>default	0.25	1	<=0.6	yes	yes	yes	this model consists in doing statistical tolerancing on permanent mean-shift
<ST> gaussian	0	1	0	no	no	yes	process fully under control !
<ST> rectg	na	1	0	no	yes	yes, low	(one example to get equiprobable distribution)
<ST> bimodal	coef	1	to set	yes	no (1)	yes	the mean is supposed to stay excentered (1) in fact we'll consider one during verification
<ST> INWAESM	coef	1	0	no	yes	yes	the mean is supposed to vary from batch to batch
<noST>param	na	1	1	yes or no	considered	yes or no	worst case calculation, no hypothesis needed
<noST>FC	no TM	sa: 1.5 wk: 1.33 perf: 1.13	1	na	yes	none	special case where the parameter is also a FC, visible by the customer in the previous cases, the parameters did only contribute to the FC's

Fig.8: Distribution laws and statistical features main

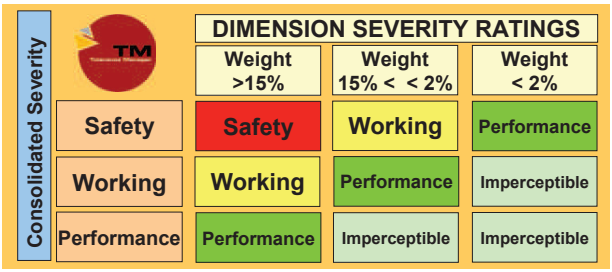


Fig. 10: Severity assignment for parameters contributing to FC

4.3.3. Summary:

The CQCS contains the functional characteristics with their importance and the statistical assumptions used in verification of design (simulation)

Here below is an example of CQCS.

2	Functional Characteristics											
2.1	Measurable											
	Type	Name	Characteristics				Severity	<ST>	Comments	Function	Drawing	Cpk worstcase	CC long term
2.1.1	Références principales / Main references												
	B	Fla0001	Tol= 0.2	None	None	None	Working	<noST> param				1	1
2.1.2	Références secondaires / Secondary references												
2.1.3	Vue de face / front view												
	W	dia1	Dim= 4	Tol+= 0.2	Tol-= -0.2	None	Working	<noST> param				1	1
	A	Sim0002	Dim= 1	Tol+= 0.1	Tol-= -0.1	None	Working	<ST> default				1	0.3
	L	Per0001	Tol= 0.22	None	None	None /A /	Safety	<noST> param				1	1
	A	Sim0003	Dim= 2	Tol+= 0.11	Tol-= -0.11	None	Working	<noST> param				1	1

Fig. 11: Part of CQCS example

Test strategy: For each measure the designer must be able to make a decision of acceptance, possibly with complementary verification tests (functional tests in the product environment) otherwise it is a waste. In some cases only the functional test is useful.

However, all requirements must be characterized, to leave no uncertainty in case of later deviation. It means that the components must be fully verified in one way or another.

Non toleranced dimensions are not in the CQCS. The supplier will be asked to measure and add them in the reports. If the design center uses DSSP (Digital shape sampling process (generally, obtained by laser scanning), it will not put them on the drawing but take responsibility of these features.

The main interest of DSSP is above all to ensure conformity of shapes difficult to measure, or more exactly whose interpretation of measures is difficult. The DSSP chapter will give criteria of assessment. It contains also the limit conditions defined during prototype phases. (ie distorted parts)

4.4. Risk analysis

This activity is led with the added value of Advanced Manufacturing or the supplier. Although they work closely with the designers, they are asked to formalize the feasibility.(Appendix B)

It consists in assessing the probability of occurrence of a failure, in order to rank an intrinsic criticality.

4.4.1. Inputs:

1) Information retrieved from CQCS: Severity
2) Coming from PFMEA: Probability of Occurrence
3) Coming from the Manufacturer: Correlation with other criteria

4.4.2. Output:

Intrinsic Criticality

The rule is in figure 12; we chose a table rather than a rating by risk priority number (r.p.n) as in FMEA.

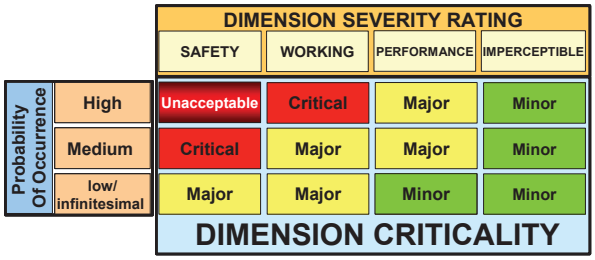


Fig 12: Criticality calculation rule

An « unacceptable » characteristic requires action plan on process or product.

Why must occurrence be confirmed? Because severity is weighted: smaller the tolerance, smaller the contribution and then the pseudo severity is low (fig. 10); with the risk to neglect it.

The probability of occurrence must counterbalance the optimism of some designers!

Summary: Intrinsic criticality is processed as follows (figure 13):

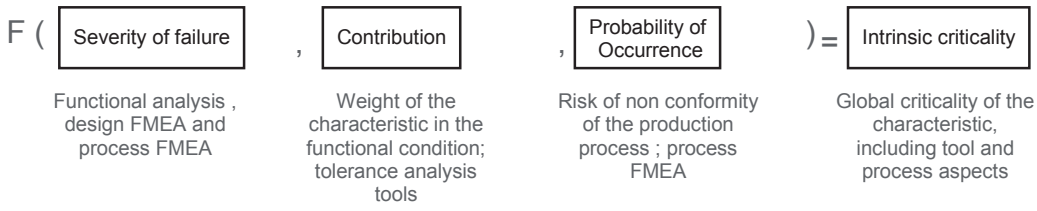


Fig. 13: Summary of criticality processing

In conclusion, MCSV retained 3 operational levels, and an implicit additional level for non toleranced dimensions.

4.5. Verification plan (VP)

This document contains the final criticality, that will define the sampling in the approval report (FAIR, Short term capability report)

The criticality can be decreased for 2 reasons:

4.5.1. FC robustness [4]:

High Cpk of the functional condition(s) attached to the functional parameter.

It makes sense to involve this characteristic in the criticality calculation.

However our tools do not manage this cause, because logically the tolerance ranges are already enlarged and the criticality should not be "critical"; so we do not decrease "a second time". Also if the risk is so low, probably the designer does not retain the FC in the FC dashboard (refer to CAT 2009 paper)

4.5.2. correlation:

When features are repeated, and manufactured in the same or similar operations, it makes sense to consider that we do not need the same depth of control on all. For critical correlated characteristics we can keep one critical and let the others become major.

The VP allows requiring Measurement process capability (=GageR&R and accuracy) to be included in the reports, and Long Term Process Capability in order to ensure that the random drift and the standard deviation do not exceed the hypothesis. (Appendix B)

4.6. Verification reports

You will find an overview in appendix D.

The characteristics are verified on 30, 5 or 1 sample according to criticality.(FAIR and STPC reports)

The critical and major characteristics are submitted to a capability study.

The capability targets are based on Cpk, Cp and absolute centering according to the statistical model defined during the design. (Appendix C).

Thresholds of Cpk for major dimensions take into account the supplier risk (NFX 06-034)

A synthesis tab in FAIR and STPC allows proper simulation of multicavities tools in our dimension chain software TM.

A mix of measured characteristics, digital sampling and functional verifications, allows making decisions more quickly than with voluminous reports disconnected with the need, and this also help continuous engineering teams to manage part evolutions and new tools acceptance more easily.

4.7. Decision making

The target of component verification is to have all FP conform to the specifications, but above all, all FC satisfied (3.2). A decision making on a component will then consider together all the FP defining the FC, this allowing the most economical decision, as we can modify some specifications to accept non conform parts as well as require others to be conform. For that we can simulate assemblies of real parts. At the end of the process, definition file and verification reports must be consistent.

5. Conclusion:

Following MCSV deployment in 2005, we observed no problems with suppliers achieving the Cpk calculated from only 5 measurements for major characteristics. An additional benefit is that it demands better accuracy of the measurements than in the past. Internal users do not require additional criticality levels, but complementary measurements (on new batches) in case of poor Cpk, to reduce customer risk. The solution to this requirement is in progress, it will provide also a view of the process deviation during approval. This finally tends toward "variable Cpk" method, but in an easier deployment context than that which existed in 2005.

Some testimonies show that MCSV:

- Ensures product quality and functional compliance,
- Accelerates part acceptance process; reduces the number of iterations to approve components,
- Improves team collaboration,
- Allows savings: Less time spent to make drawings, less time spent to analyze verification report, less measurement report purchased ,less measurement specification (when ISO 8015 is not enough), more efficient risk analysis meetings, avoid unnecessary tooling adjustments (for extra dimensions).

We hope to have convinced the reader that HCPP [1] principle optimizes the workload of the actors involved in the verification process…with higher quality.

Acknowledgements

I thank Jean Gouzy and, Philippe Delcambre as owners and promoters of “lean design” in Schneider Electric, they have made MCSV efficient and even, applicable.

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Merci Jean Claude Bréart, father of the new HCPP standard, to contribute to the formalization and recognition of the concepts.

MCSV is indebted to Olivier Dardare, precursor of most of MCSV concepts.

Thanks to MPQ project team, and the MCSV network, whose members are at the origin of the specifications.

I do not forget Naveen and Iain, who have kindly reviewed this document on the form and content.

References

[1] Revue de statistique appliquée, Tome 8, n°4 (1960) , M. Forestier, « Une carte de contrôle siplifiée » p.69-81

[2] internal procedure , DIT X F règles d’acceptation, & formulaire de cotation statistique, Olivier Dardare 2000,

[3] Maurice Pillet ,Appliquer la maitrise statistique des procédés, Editions d’Organisation, ISBN 2-7081-2672-5, 1995-2000-2002

[4]prNF E 04 -009, Hierarchical organization of product/process characteristics, hiérarchisation des caractéristiques produit-process (HCPP) UNM, AFNOR 2011, to be published in 2012.

[5] XP E 04-008, Geometrical Product Specifications (GPS) — Tolerance allocation method, indications and acceptance criteria — Methods based on arithmetics, quadratic statistics and inertial statistics, AFNOR, September 2009.

Appendix A: Screen copy of Tolerance manager (from PCO Innovation)

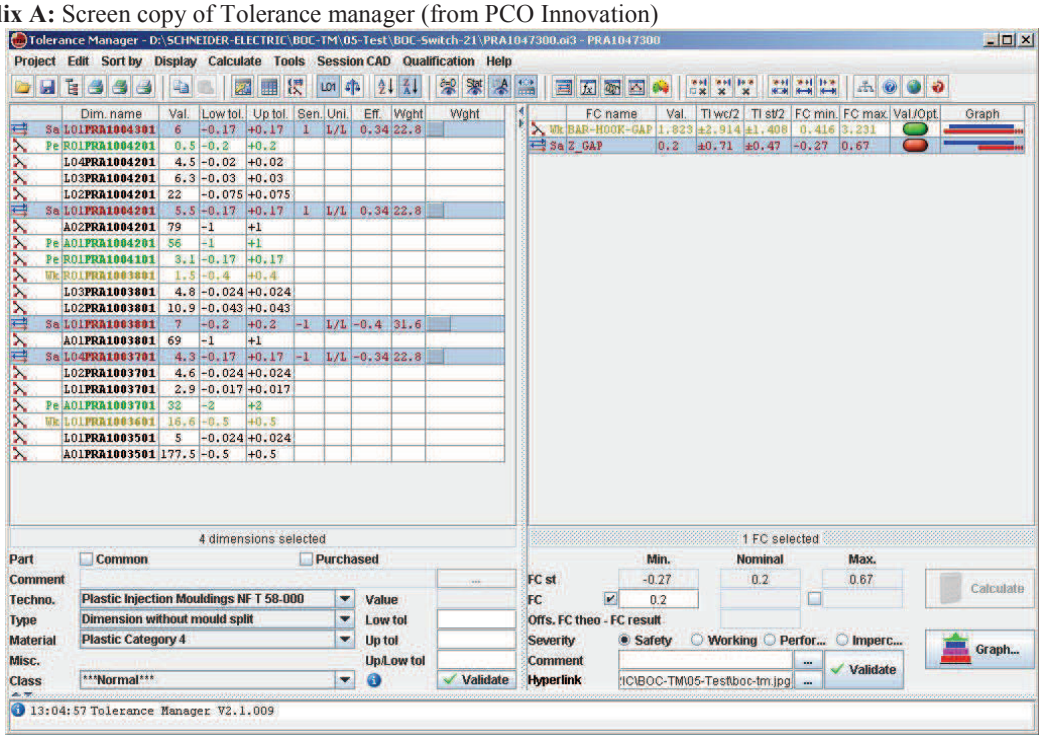


Fig.14: Screen capture of Tolerance manager showing the pseudo-severity of the parameters (left column)

Screen capture of Tolerance manager showing the pseudo-severity of the parameters (left column)

It is calculated according to the severity of the functional(s) condition(s) (right column) and the contribution of the parameter Sa=Safety, Wk=working, Pe=performance. On the selected FC, the weights are >15% so original severity level is kept for each contributor.

Appendix B:

Global view of the risk analysis assessing each CQCS criteria, and deduced verification plan and CQCP

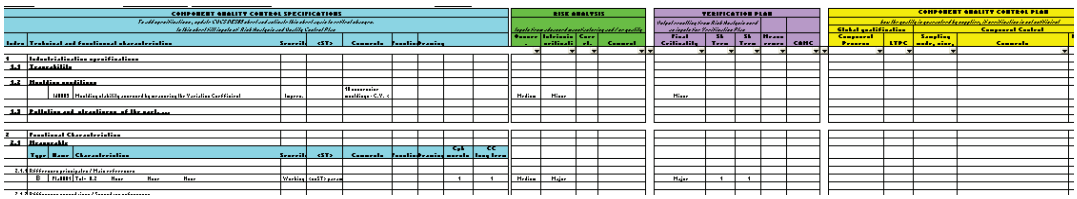


Fig.15: Risk Analysis/VP/CQCP tab

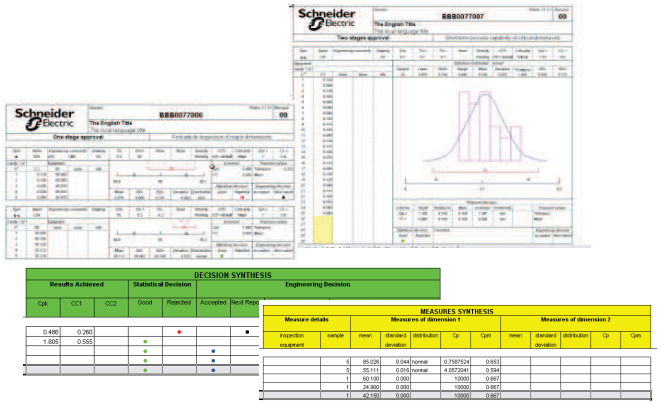
Appendix C: Short term indicators required by Phenix, deduced from long term indicators and from ST models.

Example	Process	Theoretical Model	TM Model	TM Settings	Phenix Dispersion	Phenix Centering	Tool Risk	Comments
Machining axis to axis	Perfectly centerable Under control	Gaussian	GAUSSIAN	n = 6	Cpk ≥ 1	CC = 0 + tolerance	No	No tool risk
	Centerable Small random offsets (TM coef)	No standard industry model	INWAESM	n = 6	1 ≤ Cpk ≥ f(coef) (example: Cpk 1.33 for coef 0.25)	CC = 0 + tolerance for long term	No	
Height dimension by grinding	Process with constant offset, periodically recenterable by operators (ie. wear followed by resharpening)	Probabilistic	EQUIPROBABLE	None	Cpk ≥ 1 instantaneous	CC = 0.99 No Cc inspection	Negligible	
New Process	Unknown distribution	Worst case	NON STATISTICAL	-	Cpk ≥ 1 instantaneous	CC = 0.99 No Cc inspection	No	
Molding	- Constant random offset due to cavity - In addition, dimensions can shift a little	Pure 1/2 Quadratic (project team decision)	BIMODAL	Coef = 0.6 advised n = 6 Coef accord. to tech	Cpk ≥ 1.33 but Cp warning	CC = Coef = 0.6 Advised	Nil or Negligible	
Molding	- Constant random offset due to cavity - In addition, dimensions can shift a little	Statistical 1/2 Quadratic (project team decision)	INWAESM	Coef = 0.25 by défault n = 6	Cpk ≥ 1.33 but Cp warning	CC = 0.6 by default	Yes	Tool risk
			INWAESM	Coef = 0.6 n = 6	Cpk ≥ 1.33 but Cp warning	CC = 0.6 by default	Yes	
			BIMODAL	Coef = 0.35 n = 6	Cpk ≥ 1.33 but Cp warning	CC = 0.6 by default	Yes	

Fig.16: Advised distribution laws according to the technology

"Tool risk" is the risk taken by statistical tolerancing of the permanent mean shifts (generally ST default setting). Indeed, bimodal (half quadratic) carries no risk but is severe because it manages the means in worse case. To prevent the tool risk, and detect simulation need, the Cpm indicator is used as a warning [5].

Appendix D: reports overview
(Complementary verification test report is not shown)



FAIR and STPC reports

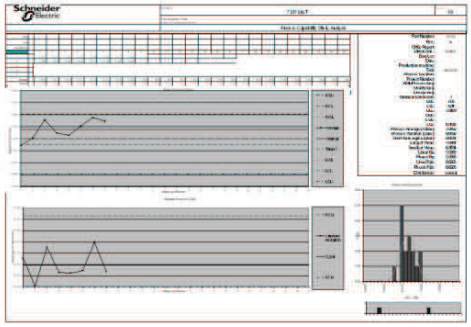


Fig.17: Long term process capability report

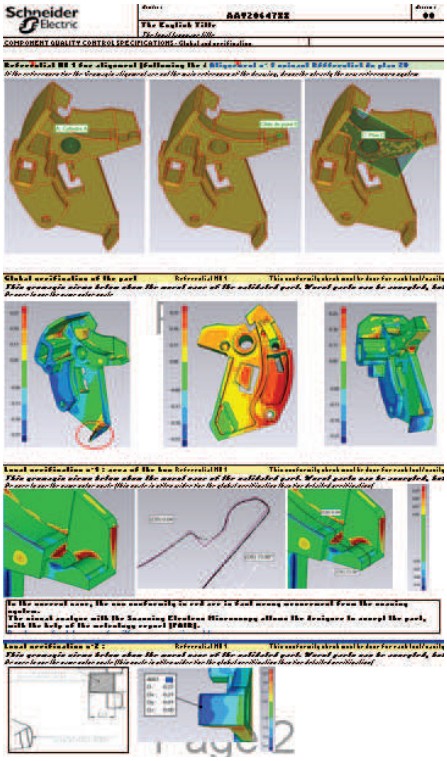


Fig.18: VDSSP tab

Appendix E:where does the 15% limit come from ?

The objective of the verification is to detect the variation of centering and the variation of dispersion from the nominal.

Let's examine a parameter x_1 involved in a functional condition (FC) calculated in statistics, ie from the variances .

Its sensitivity coefficient is $k_1 = \frac{\partial FC}{\partial x1}$ *(1)* The definition of its weight $w_1 = \frac{k1^2.\sigma1^2}{\sigma CF^2} = \frac{k1^2.\sigma1^2}{\sum ki^2.\sigma i^2}$ *(2)*

The non conform rate (ncr) of x_1 is function of: 1-F(x) , with F distribution of the reduced normal law, x being itself a function of the specification limit.

Let's study first a **variation of centering** (mean-shift)

A drift δ on x_1 will affect the ncr of x_1 as follow: ncr_{x1} =1-F(x-δ) *(3)*

This drift will shift the FC according to $k_1.\delta$

The ncr of the FC , will be affected as: $ncr_{FC} = 1 - F(x - \frac{k1.\delta.\sigma 1}{\sigma FC}) = 1 - F(x - \delta.\sqrt{w1})$ *(4)*

We can verify[1] that the impact of δ on the ncr_{fc} is function of $\sqrt{w1}$: $\frac{\partial ncr_{FC}}{\partial ncr_{X1}} = \sqrt{w1}$ *(5)*

nota: $\sqrt{w1}$ is called "effect".

If we study the variation of ncr_{fc} according to δ , we observe that $\frac{ncr_{FC}}{ncr_{X1}}$ decreases first and then converges to 1, ie that at this moment parts non conform make 100% of assemblies not conform.

We have to consider that tolerance ranges of x_1, are defined in a relevant way and be interested by small variations, and so keep $\sqrt{w1}$.

Let's now study the impact of a **variation of σ_{x1}**: $ncr_{X1} = 1 - F(x.\frac{\sigma x1}{\sigma' x1})$ *(6)*

In the same way, $ncr_{FC} = 1 - F(x.\frac{\sigma FC}{\sigma' FC})$ *(7)*

We saw that : $\frac{\partial \sigma fc}{\partial \sigma x1} = \sqrt{w1}$ *(8)*

However, we can verify that $\frac{\partial ncr fc}{\partial ncr x1} = w1$ *(9)*

We can now calculate the ncr of a dimension able to produce a defined level of ncr on the FC.

The tables below (figure 19_show the necessary ncr_{x1} function of its weight and function of the severity of the FC.

According to fig. 6 the maximum level of ncr_{FC} is limited to 3.4, 34 or 340 ppm.[2]

weight	SQR(weight)	safety 3.4	working 34	performance 340
0.01	0.1	34	340	3400
0.02	0.141421356	24	240	2404
0.05	0.223606798	15	152	1521
0.1	0.316227766	11	108	1075
0.15	0.387298335	9	88	878
0.2	0.447213595	8	76	760
0.25	0.5	7	68	680
0.3	0.547722558	6	62	621
0.35	0.591607978	6	57	575
0.4	0.632455532	5	54	538
0.45	0.670820393	5	51	507
0.5	0.707106781	5	48	481
0.55	0.741619849	5	46	458
0.6	0.774596669	4	44	439
0.65	0.806225775	4	42	422
0.7	0.836660027	4	41	406
0.75	0.866025404	4	39	393
0.8	0.894427191	4	38	380
0.85	0.921954446	4	37	369
0.9	0.948683298	4	36	358
0.95	0.974679434	3	35	349
1	1	3	34	340

For drift δ

weight	safety 3.4	working 34	performance 340
0.01	340	3400	34000
0.015	227	2267	22667
0.05	68	680	6800
0.1	34	340	3400
0.15	23	227	2267
0.2	17	170	1700
0.25	14	136	1360
0.3	11	113	1133
0.35	10	97	971
0.4	9	85	850
0.45	8	76	756
0.5	7	68	680
0.55	6	62	618
0.6	6	57	567
0.65	5	52	523
0.7	5	49	486
0.75	5	45	453
0.8	4	43	425
0.85	4	40	400
0.9	4	38	378
0.95	4	36	358
1	3	34	340

For variation of σ

Fig. 19

For high weights the dimension x_1 keeps the pseudo-severity attached to the FC, symbolized by a colour. *As soon the ncr_{x1} is close to the ncr_{FC} of the next column, we consider that the pseudo severity of x_1 is decreased of one step.*

[1] By derivation of the polynomial approximation of F, or more simply by Excel simulation.

[2] Example : a dimension with a weight of 50% must vary of 48 ppm by a drift to make vary the FC of 34 ppm. For the same its standard deviation must present a ncr of 68 ppm to make the same effect.

MCSV has retained the thresholds of the right table, because the drift of the mean is mastered with a smaller sample than the standard deviation, even if the effect of a drift is more critical.
Important: you notice that the thresholds are valid only for ranges of ncr_{FC} on a scale of 10.